AN EASY-TO-USE SIMULATION TOOL FOR INDOOR APPLICATIONS POWERED BY PHOTOVOLTAIC SOLAR CELLS

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1) Context / Study motivation

Low power devices, focused towards indoor applications, face serious challenges in terms of harvesting nearby natural sources of energy for power. Examples are router nodes, sensor and communication networks, camera networks, … Nowadays, these wireless systems use batteries as source of energy. These batteries need to be replaced in due time and this factor plays a major role in determining the life of the device. Often, the cost of replacing the battery outweighs the cost of the device itself. In order to obtain an "infinite" lifetime of the system, the device should be able to harvest energy from renewable resources in the device's environment. Photovoltaic (PV) energy is an efficient natural energy source for outdoor applications. However, for indoor applications, the efficiency of classical crystalline silicon PV cells is much lower. Typically, the light intensity under artificial lighting conditions found in offices and homes is less than 10 W/m² as compared to 100-1000 W/m² under outdoor conditions. Moreover, the spectrum is different from the outdoor solar spectrum. Although the crystalline Si cell is still dominating the PV market, second generation solar cells, i.e. thin film technologies, are rapidly entering the market. The different PV cells are rated by their power output under standard test conditions (AM1.5 global spectrum and light intensity of 1000 W/m²) but those conditions are not relevant for indoor applications. Unfortunately, there are no international norms which determine the way of characterizing solar cells for indoor applications. The question therefore arises: which type of solar cell is best for which indoor device? To answer this question, an easy-to-use simulation tool was written which compares the power output of different types of solar cells for typical artificial light sources, taken into account the power requirements of different devices and different types of energy buffers.

2) Description of approach and techniques

A solar-powered application consists of the following components: (i) the external environment, (ii) the solar module, (iii) energy storage and (iv) the device (figure 1). The simulation tool, writtin in C#, allows the user to set up the parameters of each of these four components. Among others, these are (i) the different light sources, with their light spectrum, intensity (in lux) and time use, (ii) the characteristics of the solar cell, (iii) the characteristics of the energy buffer (primary/secundary battery or capacitance) and (iv) the power requirements and duty cycle of the device. Predefined common used values are embedded within the tool, but the user can change them at will. Figure 2 shows a screenshot from the simulation tool.

We use the simulation tool for comparing the power output of different solar cells (amorphous Si [1], CdTe [2], CIGS [3], GaAs [4] and an organic cell with active layer P3HT:PCBM [5]) with the classical crystalline silicon solar cell as reference [6]. This comparison is made for typical artificial light sources, i.e. an LED lamp, a "warm" and a "cool" fluorescent tube and a common incandescent lamp, which are compared to the outdoor AM 1.5 spectrum as reference. The comparisons in the programme are based on the quantum efficiencies of the solar cells and the light spectra of the different light sources. They do not (yet) include the non-linear effects of low-intensity lighting. Using the results of the tool, one can obtain guidelines to investigate whether it is realistic to power a certain low power device with PV cells.

3) Results / Conclusions / Perspectives

As example, we compare the indoor environments to the outdoor spectrum AM 1.5 (figure 3). We notice that the incandescent lamp is the best artificial light source. For a Si and CIGS cell, the performance of the solar cell improves with a factor of almost 3 compared to AM 1.5. This was to be expected because the incandescent lamp has the highest intensity within the absorption window of the solar cells. The LED lamp is the worst light source for indoor PV with a decrease in performance of a quarter for amorphous silicon to two thirds for crystalline silicon cells. The reason is that an LED lamp is a very efficient light source: it emits only light within the visible region, from 400 to 800 nm.

The best solar cells for indoor use depend heavily on the light source. Figure 4 shows the relative efficiency of each cell to the silicon cell as reference, for each lighting condition. For an incandescent lamp and in an outdoor environment, crystalline silicon remains the best. However, in the other environments, GaAs and CdTe are significantly better.

An important conclusion is that, depending on the light source, broadening the absorption window is not always beneficial. The CIGS cell with a wider absorption window than the CdTe cell performs worse in an LED environment. Indeed, a wider absorption window will lead to more absorbed photons (and thus a higher current), but will lower the useful energy of each photon (lower voltage). Broadening the absorption window is beneficial in an outdoor AM 1.5 environment and for an incandescent lamp. For an environment with LED lamps or fluorescent tubes, a too broad absorption window deteriorates the power output.

To indicate the possibilities and restrictions of the tool, we discuss in the paper the case studies of powering a ZigBee module and a wireless repeater with different types of solar cells, under several common light conditions and battery characteristics.

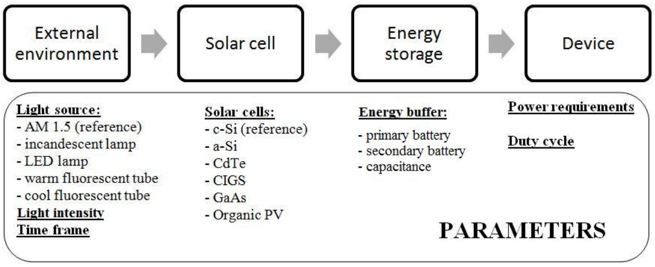

Figure 1. Simplified schematic overview for powering a device with solar cells. The varying parameters in the model are indicated.

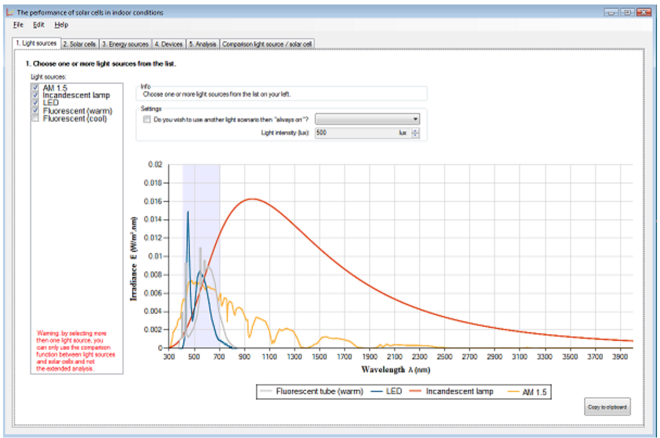

Figure 2. Screenshot from the simulation tool: the selection of different light sources for comparison.

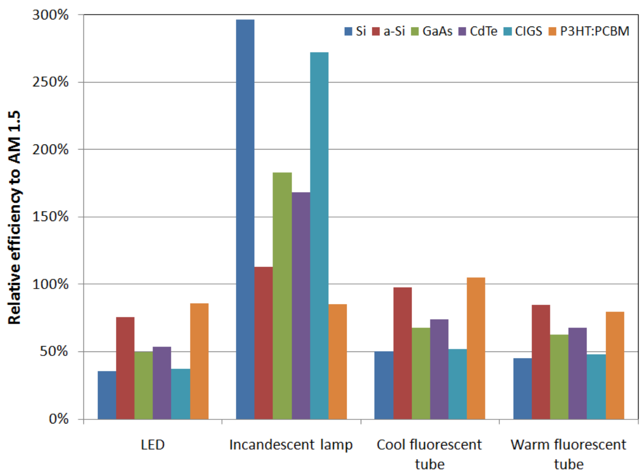

Figure 3. The relative efficiency of different types of photovoltaic solar cells in different lighting conditions, compared to the AM 1.5 spectrum as reference.

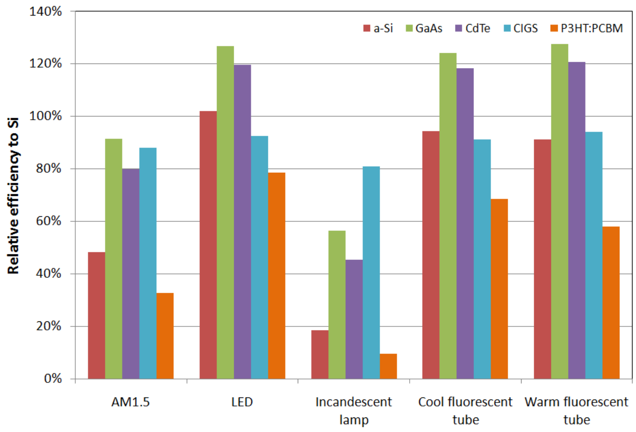

Figure 4. The relative efficiency of different types of photovoltaic solar cells in different lighting conditions, compared to the crystalline silicon solar cell as reference.

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